Field Evaluation of Low-E Storm Windows

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ABSTRACT

A field evaluation comparing the performance of low emittance (low-e) storm windows with both standard clear storm windows and no storm windows was performed in a cold climate. Six homes with single-pane windows were monitored over the period of one heating season. The homes were monitored with no storm windows and with new storm windows. The storm windows installed on four of the six homes included a hard coat, pyrolitic, low-e coating while the storm windows for the other two homes had traditional clear glass. Overall heating load reduction due to the storm windows was 13% with the clear glass and 21% with the low-e windows. Simple paybacks for the addition of the storm windows were 10 years for the clear glass and 4.5 years for the low-e storm windows.

INTRODUCTION

It is estimated that 43% of all residential windows are single-pane glass.[1] The inherent inefficiency of single-pane windows due to poor insulating value, high solar heat gain, and air infiltration—combined with the large number of homes having single-pane windows—creates a tremendous opportunity to provide energy savings to a large segment of the housing stock, many of which are moderate- and low-income households.

Storm windows are installed in over 800,000 U.S. homes annually.[2] Virtually all of these are manufactured with clear, uncoated glass. While the use of low-e coating on double-pane, sealed-insulating-glass (SIG) windows has become increasingly common over the last decade, its use in the storm window market is virtually non-existent.

Before double-pane windows became common practice in northern climates in the 1970s and 1980s, single-pane windows were the standard. Most of these homes had storm windows that would provide thermal and some amount of air infiltration benefit. Often storm windows were removed in the summer for fresh air ventilation. Over time, many storm windows would break or be removed for various reasons thereby reducing the benefit of the storm window.

Storm windows reduce conduction across a window by creating a "dead-air" space between the existing window and the storm window. In addition, storm windows help reduce infiltration which is common in leaky, older windows. Yet, many low-income weatherization programs have dismissed the benefits of storm windows and deemed double-pane replacement windows too expensive. Low-e glass incorporated into a storm window has the potential of achieving nearly equivalent window thermal performance as new windows at a much lower cost. For example, new windows may cost between $100 and $500 plus installation; a low-e storm window is in the $60 to $110 price range and is more easily installed.

OBJECTIVE

This study is designed to quantify installed costs and energy savings of clear and low-e storm windows in a cold

1. Klems, J. *Measured Summer Performance of Storm Windows*, Lawerence Berkeley National Laboratory, 2003
2. NAHB Research Center, 2006 Consumer Practices Survey

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Table 1. Storm Window Specifications

Product	Thickness, in.	Thickness, mm	Visible Transmittance	U-Factor	SHGC	Shading Coefficient	Emissivity
Clear	1/8	3	90	1.04	0.86	0.99	0.84
Low-e	1/8	3	82	0.65	0.72	0.83	0.16

Figure 1 *Subject house #4—typical 1920s and 1930s Chicago bungalow.*

Figure 2 *Single-pane, double-hung sashes with new low-e storm window.*

climate and provide guidance to home energy efficiency raters wishing to analyze storm window performance with energy simulation software.

HOUSE DESCRIPTIONS

The weatherization program in Cook County, Illinois recruited six homeowners for the study. All homes were located within a 15 mile (25 km) radius, south of downtown Chicago. Each home was a single-family detached structure having single-pane windows (with or without storm windows). All homes were constructed between 1920 and 1970 (Figure 1). All had their original single-pane windows (Figure 2). Four of the six homes had limited remaining storm windows and two had nearly 90% of the storm windows intact. All of the homes were typical Chicago construction for the period in which they were built. All had brick façades with structural concrete block exterior walls and no insulation in the walls. All had basements that were either directly or indirectly conditioned. Appendix A provides a detailed table of the homes' characteristics.

METHODOLOGY

To obtain baseline measurements, the existing storm windows were removed from all the homes (except for one window on one home). The houses were occupied during the measurement period. All occupants were instructed not to change their thermostat settings or heating patterns during the test. This enabled comparison energy used by the house before and after the storm window retrofit. Four homes were then fitted with low-e storm windows and the remaing two homes had clear storm windows installed.

Data was collected from each house to characterize energy consumption with and without storm windows. This characterization produced an equation reflecting energy usage as a function of the indoor/outdoor temperature difference. Seasonal energy use predictions based on typical meteorological conditions (assuming indoor temperature of 70°F/21°C) can then be made with before and after storm windows were installed.

Temperature sensors were placed on two of the window surfaces in order to measure the differences in temperature of the different window types. Sensors were placed on the inner surface of the outer pane (surface 2) and the inner surface of the inner pane (surface 4).

STORM WINDOWS

Two types of storm windows were installed in the test homes. Four homes received Pilkington Energy Advantage™ Low-E Glass and two homes had Pilkington Uncoated Float Glass installed. The specifications for the storm window glass are listed in Table 1.

Since nearly all the primary windows were double hung, storm windows that were openable were installed to provide for spring and summer ventilation. Storm windows were installed in a two-track frame that allowed for a movable lower storm on the inner track that could open with a screen on the outer track to keep out insects.

DATA ACQUISITION

Datalogging equipment was installed in each house to monitor key information including furnace runtime, indoor temperature and humidity, and surface temperatures of the

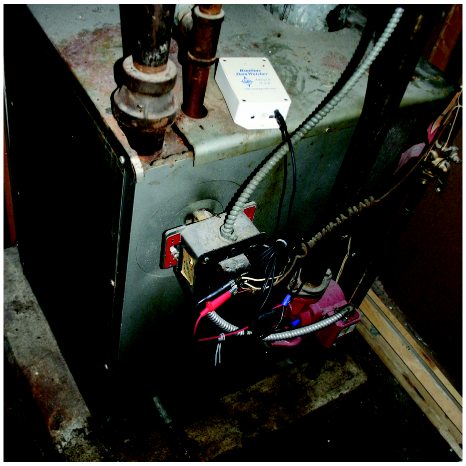

Figure 3 *Discrete datalogger to monitor boiler runtime.*

primary and storm windows. Although outdoor data was recorded at two homes, weather data from nearby Chicago Midway Airport was used as the official outdoor conditions.

Data was captured on an hourly basis. Data acquisition systems (DAS) were installed in four homes which allowed all the data to be recorded into one file. It was too difficult to run wires to a central location in the remaining two homes and, therefore, discrete loggers were employed at each datapoint. For these two homes, the information was manually gathered from each logger and the data subsequently synchronized. Furnace gas consumption rate was calibrated against the utility gas meter. Since all of the furnaces/boilers had a fixed consumption rate (see Table 2), it was assumed that the the gas runtime was directly proportional to the usage.

MONITORING

Data was collected in two phases. The baseline data was collected with the remaining original storm windows removed and the second phase began with the installation of the new storm windows.

Datalogging equipment was fully commissioned for five of the six houses in late October 2005. House #1 had a series of problems with the boiler and poor data correlation that did not allow for the energy use data to be used in the final analysis. House #6 also had data correlation problems. These happened to be the two homes with boilers, rather than forced hot air systems. Thermal mass (concrete block walls) in the homes and the delay radiators have in heating a room may have contributed to the poorly correlating data.

Pre-storm window monitoring continued until the new storm window installation that occurred between January 23 and February 7, 2006 for all six homes. Post-storm window installation monitoring continued through the end of April.

Table 2. Boiler/Furnace Energy Consumption Rates

House	Furnace/Boiler Rated Input Capacity, Btu/h (kW)	Calibrated Consumption, Btu/h (kW)
1	160,000 (46.9)	141,200 (41.4)
2	130,000 (38.1)	104,300 (30.6)
3	100,000 (29.3)	92,300 (27.1)
4	100,000 (29.3)	97,300 (28.5)
5	100,000 (29.3)	97,300 (28.5)
6	150,000 (29.3)	147,000 (43.1)

AIRTIGHTNESS TESTING

Older single-pane windows are notorious for allowing air to pass between the sash and window frame. When adding storm windows, it was assumed that this leakage path would be greatly reduced. In order to measure this difference, an airtightness test was performed before and after the addition of the storm windows (see Table 3).

Adding storm windows improved the airtightness of all six homes. Air infiltration rates were reduced between 231 and 335 CFM (393 and 570 M^3/hr) when pressurizing the home to 50 Pascals. Although reduced infiltration is not a direct benefit of the second pane of glass, it appears to be a consistent and repeatable improvement in the homes' performance. From the six houses tested, the air infitration reduction averaged from about 9 to 25 CFM_{50} (15 and 43 M^3/hr) per window.

ENERGY SAVINGS

Once the data was gathered from both pre- and post-storm window installation, energy use data could be analyzed. In order to characterize each home, trendline equations were developed for pre- and post- storm window installation. Trendline equations are listed in Appendix B. Figure 4 illustrates the resulting trendlines developed from House #4 data.

Trendlines create a relationship between energy usage and outdoor temperature. Once this relationship is established, hourly weather data can be plugged into determine an estimated energy usage. If this is carried out over an entire heating season, the energy usage can be predicted. By using ASHRAE BIN weather data[3] (reference Appendix C) for an average Chicago heating season, resulting energy savings can be calculated by subtracting the annual heating energy usage difference with and without storm windows (see Table 4).

Energy savings were only calculated based on the reduced gas usage. No effort was made to include the coincident electric savings related to reduced runtime of forced air blower motors or hydronic pump motors. The local natural gas cost in spring 2006 was $1.39 per therm (1 therm = 100,000 Btus = 29.3 kWh)

[3] ASHRAE, *2005 ASHRAE Handbook—Fundamentals*, Chapter 32.22. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Table 3. Before and After Airtightness Testing Results

House	Before Storm Windows CFM (M^3/hr) at 50 Pa	After Storm Windows CFM (M^3/hr) at 50 Pa	% Reduction
1	5,230 (8,891)	4,930 (8,381)	5.7%
2	4,759 (8,090)	4,459 (7,580)	6.3%
3	3,159 (5,370)	2,900 (4,930)	8.2%
4	4,930 (8,381)	4,595 (7,812)	6.8%
5	3,590 (6,103)	3,359 (5,710)	6.4%
6	3,850 (6,545)	3,520 (5,984)	8.6%

Table 4. Storm Window Energy Savings

	Percent Energy Savings	Reduced Therm Usage	Annual Savings (at $1.39/Therm)	Glass Area, ft^2 (m^2)	Therms Saved per ft^2 (m^2)
House 1* – low-e	27%	432	$600	132 (12.3)	3.27 (35.2)
House 2 – low-e	19%	353	$490	72 (6.7)	4.90 (52.7)
House 3 – Clear	8%	80	$111	107 (9.9)	0.75 (8.1)
House 4 – Clear	18%	228	$317	62 (5.8)	3.68 (39.6)
House 5 – low-e	23%	245	$341	58 (5.5)	4.23 (45.5)
House 6* – low-e	19%	105	$145	65 (6.0)	1.61 (17.3)

* Homes 1 and 6 did not have very high daily temperature to gas usage correlation coefficients requiring them to be removed from the final energy data analysis.

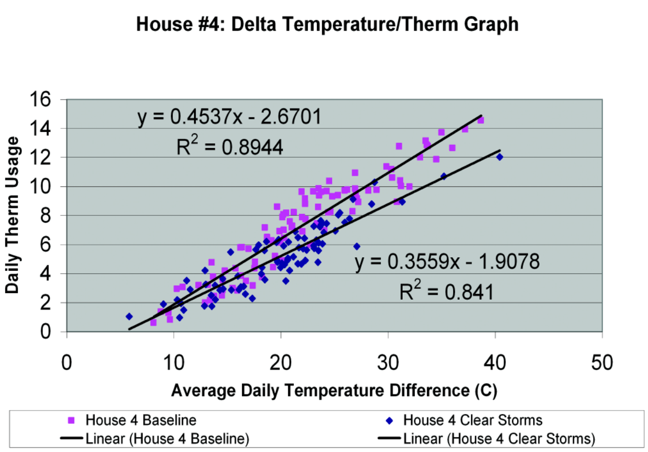

Figure 4 *House #4: delta temperature/daily therm usage graph.*

GLASS SURFACE TEMPERATURE

A side-by-side glass temperature test was conducted in House #6 in which one window was fitted with a low-e storm and the other clear glass storm. Figure 5 shows the result of this test. The side-by-side test was conducted only at House #6 because it was the only house in which temperatures were recorded at 30-minute intervals and the night-time data could, therefore, be used. For glass surface temperature comparison, it is preferable to use night-time data because the daytime solar irradiation can distort glass surface temperature measurements.

The Y-axis shows the temperature difference between the side-by-side windows in degrees Fahrenheit. Until January 23, 2006, this house had no storm windows installed. During this time period, the window that was slated to receive the low-e storm window was, on average, 2.1°F (1.2°C) colder than the window that was going to receive the clear storm window. There was a heater underneath the warmer window; therefore, it was assumed that this heater explained the systematic temperature difference noted during the baseline test. The storm windows were installed on January 23, 2006. After that point, the interior surface temperature of the window fitted with a low-e storm window was clearly warmer than the window having a clear glass storm window, even though it was consistently cooler during baseline testing. This increase in interior surface temperature for the low-e storm window indicates higher thermal comfort for the occupants and associated heating energy savings.

There was one particularly cold day, denoted by a circle in Figure 5, on February 20, 2006. The outside ambient temperature was 14°F (-10°C) and the inside temperature was 65°F (18.3°C). A nearby weather station recorded wind speeds around 2 mph (0.89 m/s). The clear glass window surface temperature was 58.3°F (14.6°C) and the low-e glass window surface temperature was 62.3°F (16.8°C). As noted earlier, there was a heater installed underneath the clear glass

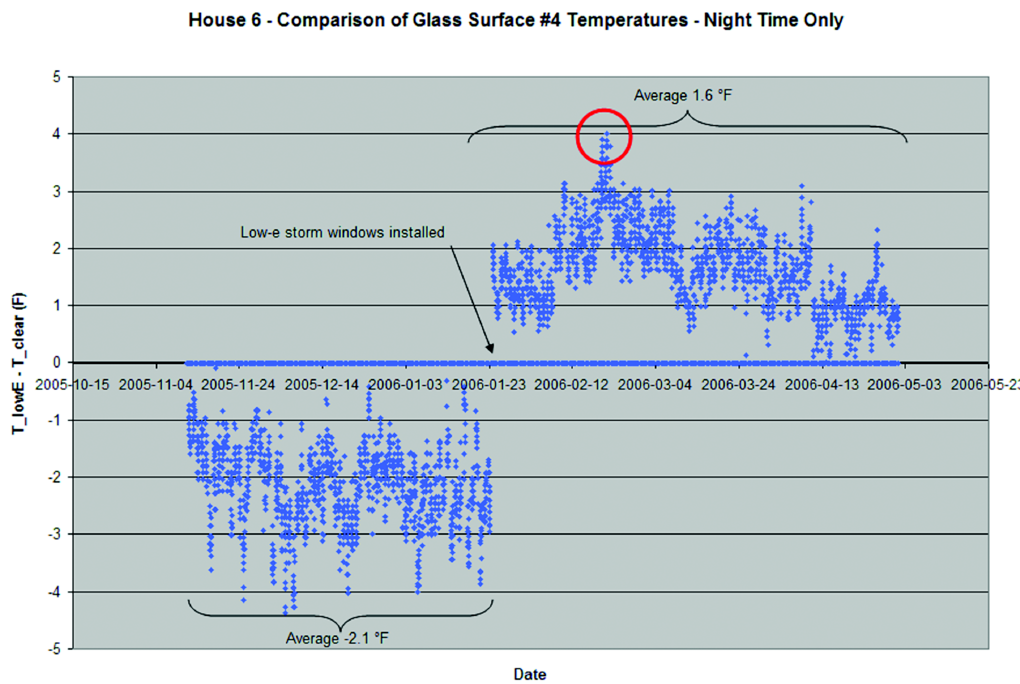

Figure 5 *Interior glass surface temperature differences at the room side (#4) for side-by-side windows having no storm windows (prior to 1/23/2006) and after one was fitted with a low-e storm window and the other with a clear glass storm window, as a function of time.*

Table 5. Center of Glass U-Factors

Center of Glass U-Factor Simulation, Btu/h·ft^2·°F	Standard NFRC Conditions*	February 20, 2006, Conditions
Clear storm window	0.49	0.42
low-e storm window	0.36	0.30

* NFRC, NFRC 100-2004, National Fenestration Rating Council, Silver Spring, MD, 2004

window, so its true surface temperature was roughly 2°F (1.1°C) colder (as shown in the baseline data in Figure 5). The surface temperature difference between these two windows on this cold night was between 4 and 6°F (2.2 and 3.3°C). The windows were simulated at these outside and inside temperature conditions in the WINDOW 5.2 software. WINDOW 5.2 predicted a difference in temperature between the two windows of 4°F (2.2°C), which closely matches the measured difference. WINDOW 5.2 calculated a 27-29% reduction in Center-of-Glass U-factor between a clear glass storm window and a low-e coated glass storm window (calculated as a SIG with a 2-inch (50mm) air space). U-factor depends strongly on wind speed. The simulated Center-of-Glass U-factors are shown in Table 5.

Glass surface temperature predictions, however, were 10°F (5.5°C) lower in the simulation than in the recorded data, which is consistent with the suspicion that a heater was mounted near or under the windows. The surface glass temperature predictions are strongly influenced by heat transfer coefficients on both sides of the glass. However, there was no data on the exact wind speed at the site during these measurements and the room air temperature near the windows, which would have helped in estimating heat transfer coefficients.

INSTALLED COST

Window costs were calculated as if they were either purchased by an individual directly from a retailer or purchased wholesale from a manufacturer and resold by an installer. Based on conversations with both manufacturers and installers, the volume discount and installer markup were comparable. Installed costs for all windows were assumed to be $45 per window. This was expected to cover both a measuring visit and installation visit. See Table 6.

COST-EFFECTIVENESS

Reduced total heating energy was significant for both the clear storm windows (13%) and the low-e windows (21%), as were the installed costs ranging between $1344 and $4691. In

Table 6. Installed Storm Window Cost

House #	Window Cost	low-e Coating	Installation	Total Cost
1 – low-e	$3206	$711	$1485	$4691
2 – low-e	$1198	$273	$540	$1738
3 – Clear	$879	$0	$495	$1344
4 – Clear	$1671	$0	$990	$2661
5 – low-e	$1197	$273	$540	$1738
6 – low-e	$1809	$515	$1080	$3404

Table 7. Cost-Effectiveness of Installed Storm Windows

	Total Window Cost	Annual Energy Savings	Simple Payback, yrs
House 2 – low-e	$1738	$490	3.5
House 3 – Clear	$1344	$111	12.1
House 4 – Clear	$2661	$317	8.4
House 5 – low-e	$1738	$341	5.1

order to determine how cost-effective the energy retrofit measures are, a simple payback analysis was performed on the four homes with well correlated data (see Table 7).

Clear storm windows had a simple payback of between 8.4 and 12.1 years, which might not be deemed cost-effective by many state weatherization programs. However, the two low-e homes had very good simple paybacks in the range of 3.5 to 5.1 years. Considering the magnitude of the savings and relatively quick payback, the low-e coated storm windows show potential as a weatherization option.

SUMMARY AND DISCUSSION

Based on the results from the field monitoring, storm windows should be considered as an energy efficiency improvement measure for homes with single-pane windows in northern climates. The data gathered from six homes in Chicago indicate that there is consistent benefit to using storm windows. Clear glass storm windows reduced the heating load by 13% with a 10-year simple payback. Low-e storm windows also showed an additional improvement on top of the clear glass benefits amounting to 21% heating savings and an average payback of less that five years. With an estimated 43% of all residential windows being single-pane glass, there is a tremendous opportunity to provide energy savings through the use of affordable storm and low-e storm windows.

One of the ancillary benefits of installing storm windows is reduced air infiltration. Based on the before and after storm window airtightness tests, the average reduction in air leakage (at 50 Pascals of pressure) was 15 CFM (25.5 M^3/hr) per window. This is a reasonable assumption that could be applied to energy modeling of prospective upgrades.

Window temperature sensors were able to directly compare interior window surface temperatures for windows fitted with low-e and clear glass storm windows. This temperature difference relates directly to reduced heat loss and energy savings. Measured temperature differences correlated fairly close to the simulated difference, thus corroborating assumed center-of-glass U-factors for single-pane windows with clear storms (between 0.49 and 0.42) and low-e storms (between 0.36 and 0.30).

This study had a fairly small sample size that was reduced to essentially four homes because of poorly correlated data. Additional research on the benefits of clear storm and low-e storm windows would be necessary to state more definitively the energy savings of clear and low-e storm windows. However, the results of this study indicate that there is a significant potential for the use of clear and low-e storm windows.

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APPENDIX A: HOUSE CHARACTERISTIC TABLE

House	Street Reference	Datalogger Type	# Stories	Heater Type	Year Built	Building Type	Conditioned ft^2 (m^2)	Window Area ft^2 (m^2)	Number of Windows	Before Airtightness cfm (m^3/hr)	After Airtightness cfm (m^3/h)
1	Whipple	Hobo Quadtemp Data Watcher	1	Hot Water Boiler	1930's	Bungalow	1625 (151)	132 (12.3)	33	5,230 (8,891)	4,930 (8,381)
2	Kedzie	Campbell Datalogger	1	Gas Furnace	1950	Bungalow	2250 (209)	72 (6.7)	12	4,759 (8,090)	4,459 (7,580)
3	Wabash	Campbell Datalogger	2	Gas Furnace	1935	Bungalow	1125 (105)	107 (9.9)	11	3,159 (5,370)	2,900 (4,930)
4	73rd	Campbell Datalogger	2	Gas Furnace	1925	Bungalow	1150 (107)	62 (5.8)	22	4,930 (8,381)	4,595 (7,812)
5	167th	Campbell Datalogger	1	Gas Furnace	1965	Ranch	2160 (201)	58 (5.5)	12	3,590 (6,103)	3,359 (5,710)
6	Perry	Hobo Quadtemp Data Watcher	1	Hot Water Boiler	1970	Bungalow	2500 (232)	65 (6.0)	24	3,850 (6,545)	3,520 (5,984)

APPENDIX B: ENERGY CONSUMPTION TRENDLINE EQUATIONS

House # – Condition	No Storms	Clear Storms (Old)	Clear Storms (New)	low-e Storms	Days of Data
1 – No Storms	y = 22192x – 31003 R2 = 0.5533				24
1 – Low-e Storms				y = 27174x – 453410 R2 = 0.7023	58
2 – No Storms	y = 21720x + 91281 R2 = 0.8475				42
2 – Low-e Storms				y = 22659x – 76170 R2 = 0.8934	79
3 – No Storms	y = 16811x – 130096 R2 = 0.9126				78
3 – Clear Storms (New)			y = 15660x – 127303 R2 = 0.9308		92
4 – No Storms	y = 25206x – 267007 R2 = 0.8944				94
4 – Clear Storms (New)			y = 19774x – 190785 R2 = 0.841		84
5 – Clear Storms (Old)		y = 13155x – 30345 R2 = 0.8513			78
5 – No Storms	y = 7665.7x + 195211 R2 = 0.7013				24
5 – Low-e Storms				y = 12024x – 32473 R2 = 0.9021	70
6 – No Storms	y = 8159.3x – 29441 R2 = 0.6216				61
6 – Low-e Storms				y = 5484.4x + 9532.4 R2 = 0.4696	19

APPENDIX C: BIN WEATHER DATA FOR CHICAGO, IL

Weather Bin		Annual Hours
Fahrenheit	Celsius	
–5/–1	–20.6/–18.3	6
0/4	–17.8/–15.6	58
5/9	–15.0/–12.8	66
10/14	–12.2/–10.0	125
15/19	–9.4/–7.2	243
20/24	–6.7/–4.4	354
25/29	–3.9/–1.7	511
30/34	–1.1/1.1	957
35/39	1.7/3.9	720
40/44	4.4/6.7	636
45/49	7.2/9.4	577
50/54	10.0/12.2	585
55/59	12.8/15.0	622
60/64	15.6/17.8	615
65/69	18.3/20.6	667
70/74	21.1/23.3	805
75/79	23.9/26.1	512
80/84	26.7/28.9	362
85/89	29.4/31.7	222
90/94	32.2/34.4	97

From ASHRAE Handbook of Fundamentals